



Decadal Survey Tier 2 Mission Study Summative Progress Report

ACE Radar

S. Tanelli¹, G. M. Heymsfield², G. S. Stephens¹,
S. L. Durden¹, E. Im¹, P. Racette², L. Li², G. Sadowy¹

1 - Jet Propulsion Laboratory / California Institute of Technology,
2 – Goddard Space Flight Center

2010



Instrument requirements

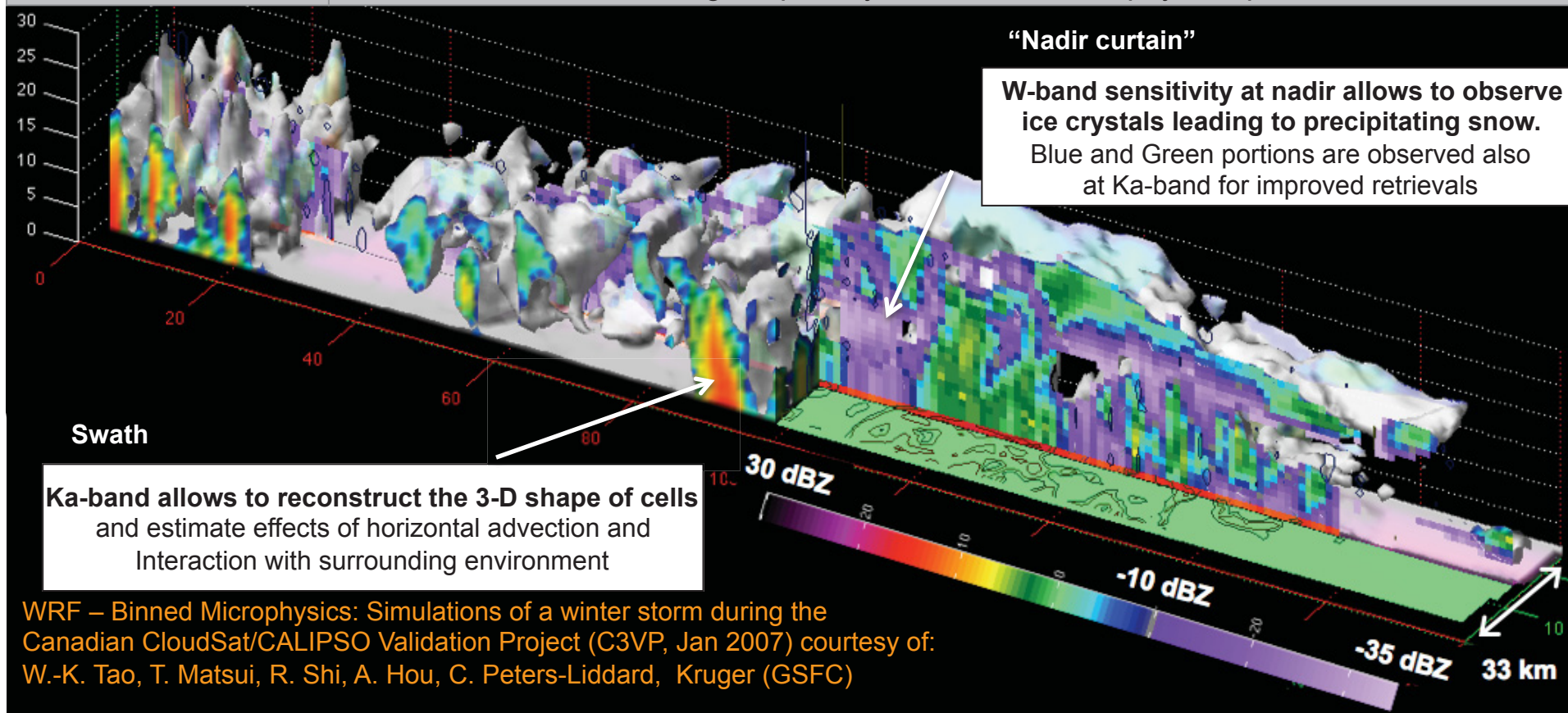


- ♦ Iterations with the Cloud Studies Team to converge on:
 - Science **requirements** achievable with technology mature enough for low-risk implementation and launch within the decade
 - Science **goals**, prioritized in order of projected scientific impact, and potentially achievable with new technologies not mature yet, but potentially within the decade.
- ♦ Result of the iterations:
 - Confirmed DS choice of operating frequencies (Ka- and W- band) as most effective in cost/performance.
 - Measurement concepts are based on existing ground-based and airborne cloud and precipitation radars
 - Desired capabilities vs. current technology: challenging trade-offs
 - ♦ Sensitivity vs. Scanning, Doppler vs. Scanning, Scanning vs. Polarization
 - ♦ Dual-goal approach adopted: one set for nadir curtain, one set for off-nadir
 - **All requirements plus a subset of goals is achievable with current technology.**
 - ♦ There are areas of **technological improvement** that are clearly **within reach** and could **increase the number of achievable goals** and/or **reduce mission risk/cost** .

The primary role of the radar is to profile clouds and precipitation.

The cloud science requirements map into the following instrument properties:

Instrument property	L2B		L2C	
Dual-Frequency	<ul style="list-style-type: none">Liquid water content	<ul style="list-style-type: none">Microphysics of the whole cloud-precipitation continuum	<ul style="list-style-type: none">Latent and Radiative Heating Rates	<ul style="list-style-type: none">Characterizing processes of precipitating clouds ..Convection-anvil mass fluxes ...
Doppler	<ul style="list-style-type: none">Particle type & sizeProcess type			
	<ul style="list-style-type: none">Convective Motion			
Scanning (goal)	<ul style="list-style-type: none">Convective cell structure, statistics of broken cloud fields in 3D			... in 3D
Range resolution	Surface precipitation, microphysical processes in geometrically thin clouds			
Horiz. Resolution	Characterizing coupled dynamical and microphysical processes			



WRF – Binned Microphysics: Simulations of a winter storm during the Canadian CloudSat/CALIPSO Validation Project (C3VP, Jan 2007) courtesy of: W.-K. Tao, T. Matsui, R. Shi, A. Hou, C. Peters-Liddard, Kruger (GSFC)



Radar studies team: philosophy



♦ Develop a baseline radar concept capable of meeting requirements with mature technology

- *Maximize leverage of other missions and technology*

Mission	STATUS	HERITAGE/LEVERAGE
CloudSat CPR	Operational since 2006	Technology & algorithms
EarthCARE CPR	NET 2014	Technology & algorithms
GPM/DPR	NET 2013	Algorithms

- *Low risk implementation for a pre-2020 launch (i.e., 2018)*
- *ACERAD (IIP'07, S. Durden, PI) instrument concept:*
 - ♦ meets all ACE requirements, but does not meet all the goals
 - ♦ provides a dataset vastly superior to its predecessors.

♦ Identify technology areas:

- *to enable an improved instrument capable of addressing all SWG goals.*
- *To reduce mission cost, risk, power consumption and data rate*



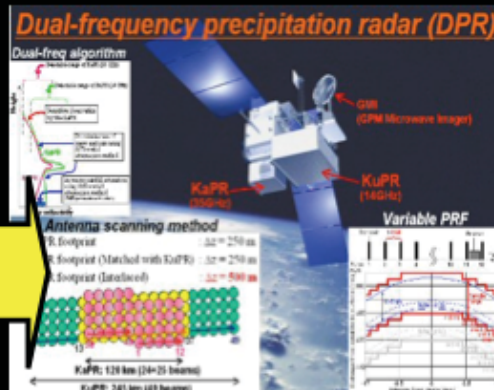
Cloud and Precipitation Radars in Space



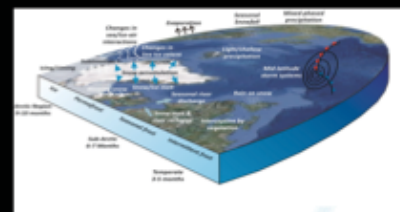
TRMM/PR – NICT/JAXA
Ku, Scanning, Tropical Rain



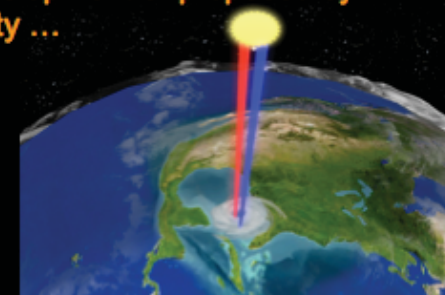
GPM/DPR – NICT/JAXA
Ku/Ka, Scanning, Precipitation



Some concepts under development or proposed by the international community ...



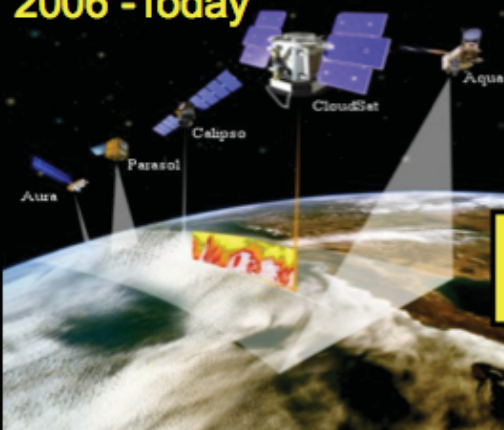
SnowSat / PPM
W/Ka, (Doppler)



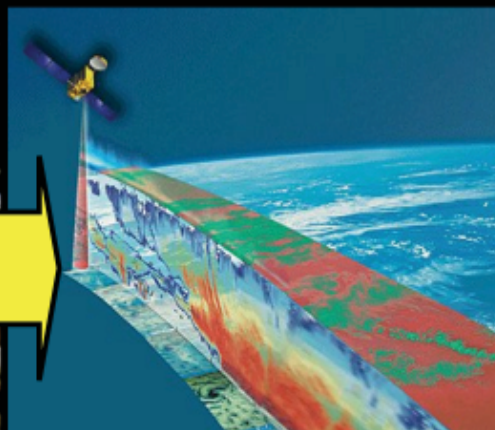
NIS
W/Ka, Scanning,
Doppler, GEO

CloudSat/CPR – JPL/NASA/CSA
W, -30dBZ, Clouds

2006 -Today

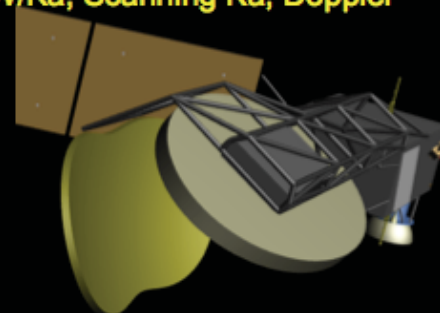


EarthCARE/CPR – NICT/JAXA
W, Doppler, Clouds

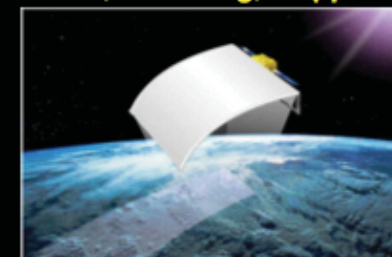


ACE Radar
W/Ka, Scanning, Doppler

ACE – ACERAD concept
W/Ka, Scanning Ka, Doppler



ACE –
Phased Array concepts
W/Ka, Scanning, Doppler



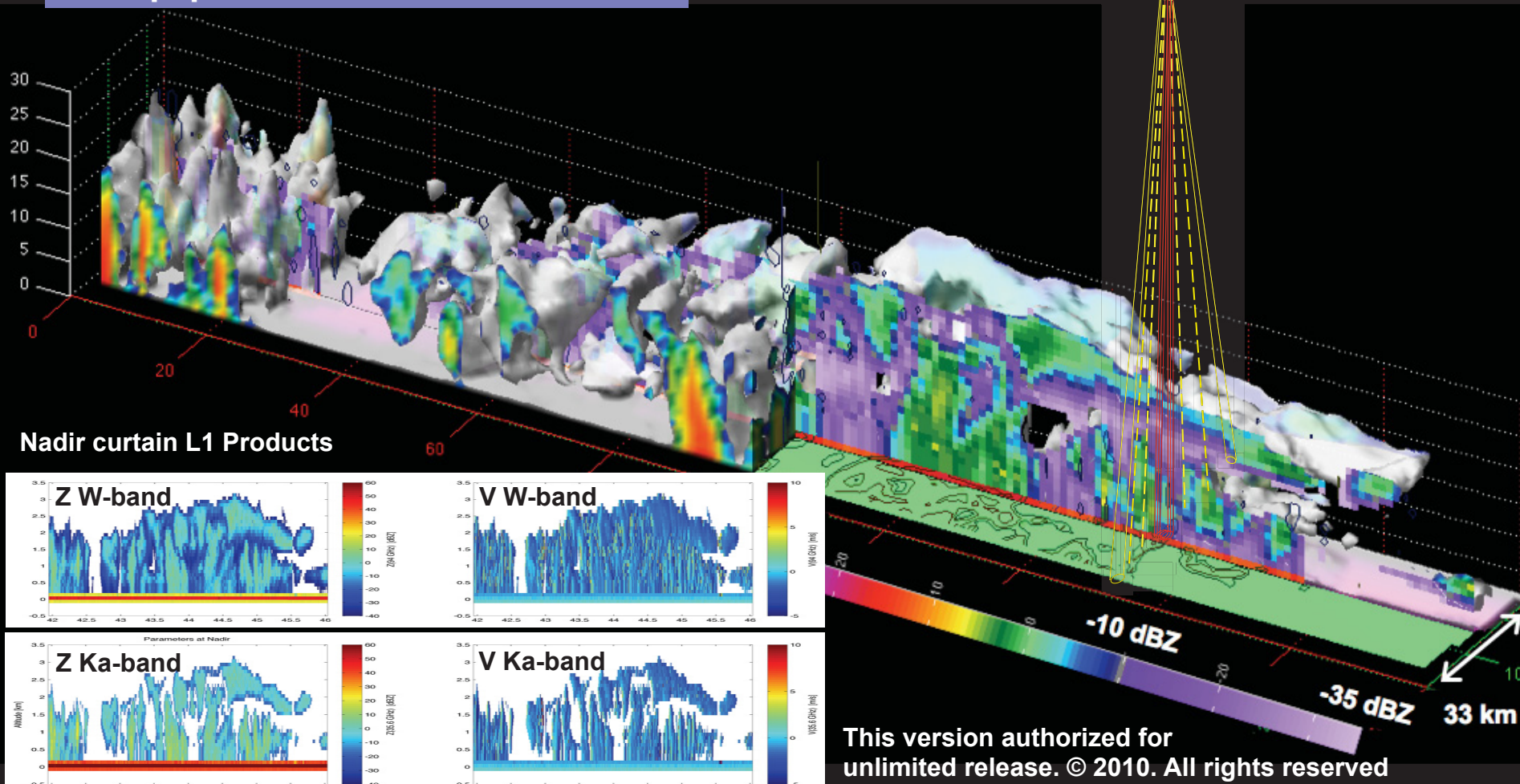
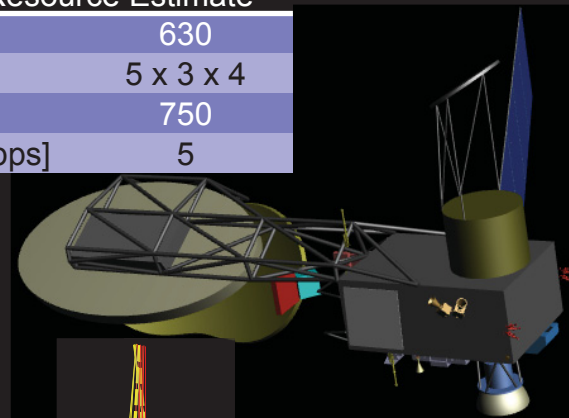
ACERAD

W-band	Ka-band
94 GHz	35.6 GHz

Sensitivity [dBZ]	-35	-12 ^(nadir)
Doppler Accuracy [m/s] (SNR>10dB)	0.2	0.5
Range Res [m]	250	
Hor Res [km]	1 x 0.7	1 x 1.8
Swath [km]	0.7	33

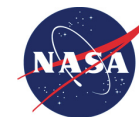
Instrument Resource Estimate

Mass [kg]	630
Envelope [m]	5 x 3 x 4
Power [W]	750
Data Rate [Mbps]	5





Instrument requirements & goals



	PARAMETER	UNIT	REQUIREMENT	GOAL (#Priority)	ACERAD	Science Mnemonic
W-band, nadir	Min Det Sens	dBZ	-35	-40 (#3)	-35	EarthCARE level of detection.
	Doppler Acc	m/s	0.4	0.2(#2)	0.2	Precipitating/non-precipitating, sedimentation, cloud scale entrainment.
	Vert Res	m	250	100 (#1)	250	Melting layer, geometrically thin clouds, in-bin attenuation
	Sfc Cltr max hgt	m	500	250 (#1)	400	Cloud base vs surface precipitation.
	Hor Res	km	1 x 1	--	0.7 x 1	CRM scale.
	Polarimetry (LDR)		--	YES (#5)	YES	Mixed phase and multiple scattering.
W-band, off-nadir	Swath Width	km	--	≥2 (#4)	--	Convective cell resolution (10km), radiometer footprint (25km). Ka-radar footprint (2km)
	Min Det Sens	dBZ	--	-20	--	All light precipitation, most large particle clouds.
	Doppler Acc	m/s	--	1	--	
	Vert Res	m	--	250	--	
	Hor Res	km	--	1 x 1	--	
Ka-band, nadir	Min Det Sens	dBZ	-10	-20 (#2)	-12	Most (all) light precipitation, some (all) large particle clouds.
	Doppler Acc	m/s	1	0.5 (#3)	0.5	Rain/no rain, convection.
	Vert Res	m	250	100 (#4)	250	
	Sfc Cltr max hgt	m	500	250 (#4)	400	
	Hor Res	km	2 x 2	1 x 1	1.8 x 1	CRM scale / matched beam.
	Polarimetry (LDR)		--	YES (#5)	YES	
Ka-band, off-nadir	Swath Width		--	>25 (#1)	33	Convective cell resolution, radiometer footprint.
	Min Det Sens	dBZ	--	-10	-10	100km would achieve meso-scale features.
	Doppler Acc	m/s	--	1	1	
	Vert Res	m	--	250	250	
	Hor Res	km	--	2 x 2	1.8 x 1	

	Requirement not met
	Requirement met
	Goal met



ACERAD heritage and technology investments

RF Transmission Line:

W-band single-pol QOTL: CloudSat, EarthCARE

Dual-Pol QOTL: ACERAD (IIP'07)

W-/Ka-band Frequency Selective Surface: ACERAD (IIP'07)

Ka-band T/R switches and wg: PR-2 (IIP'98, ATIP'99),
GLISTIN (IIP'04)

High Power Amplifier:

CloudSat, EarthCARE,
ACERAD (IIP'07), SWOT

Digital:

CloudSat, Onboard Processor-FPGA
(AIST'99), Doppler-FPGA(AIST'02)

Collimating Antenna:

Open Cassegrain/offset:
CloudSat/EarthCARE

Dragonian: ACERAD (IIP'07)

Rx chain

Receiver: CloudSat,
EarthCARE, PR-2 (IIP'98),
ACR, CRS, GPM, etc..

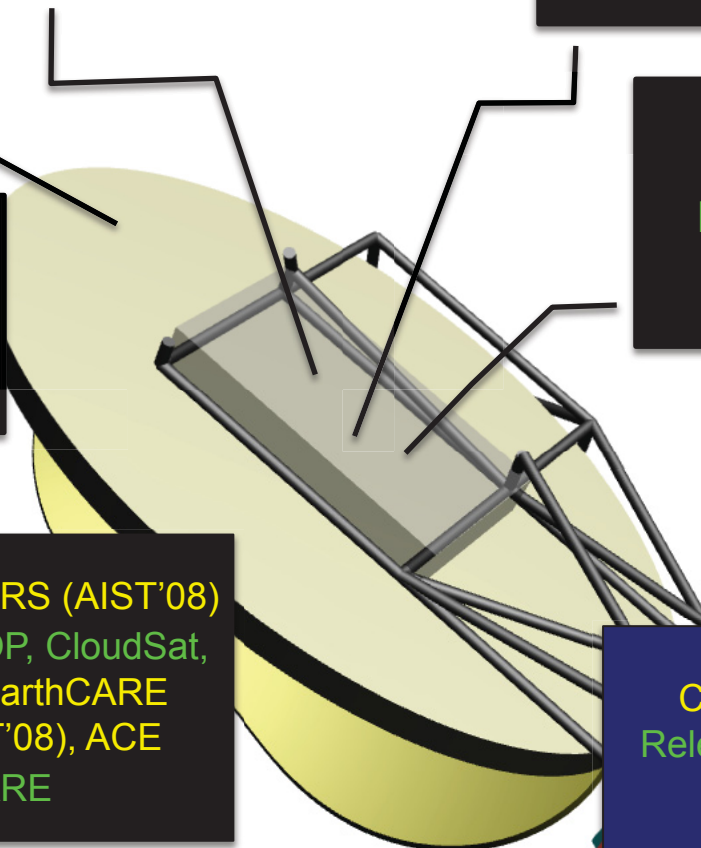
System: CloudSat, EarthCARE, ISSARS (AIST'08)

Algorithm: PR-2 (IIP'98), CRS+EDOP, CloudSat,
APRA (IIP'01), NIS (IIP'02), GPM, EarthCARE
(SALMON/USPI'08), ISSARS (AIST'08), ACE

Cal/Val: CloudSat, EarthCARE

LEGEND

Current technology investment
Relevant heritage at TRL 6 or more
Direct technology heritage





ACERAD: IIP'07 Progress



◆ Dual-Polarization W-band Quasi-Optical Transmission line

- *design completed, prototype implemented, testing in progress.*
- *TRL 4, expected TRL 6 in 2011.*

◆ W-/Ka-band Frequency Selective Surface

- *design completed, prototype implemented, testing in progress.*
- *TRL 4, expected TRL 6 in 2011.*

◆ High-efficiency Dragonian Antenna

- *design completed, prototype under implementation*
- *TRL 3, expected TRL 5 in 2011.*



ACERAD: Payload configuration



- ♦ The latest mission configuration studies show that ACERAD could be deployed in the selected launcher class **without deployable parts**.



Algorithm Development



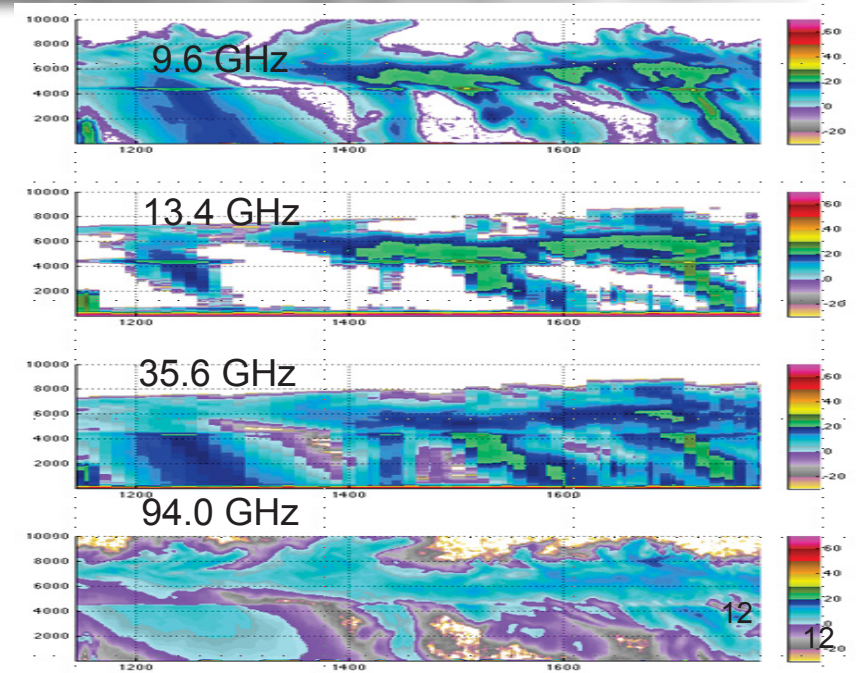
- ◆ Radar algorithms development will benefit from **extensive heritage** from airborne and ground based radars and leverage on other missions.
 - ❑ *APR-2 (IIP'98), CRS+EDOP, HIWRAP (IIP'04)*
 - ❑ *GPM, EarthCARE, CloudSat*
 - ❑ *A-Train multi-instrument algorithms*
- ◆ However – the following tasks are necessary:
 - ❑ *Advanced forward models*
 - ❑ *Retrieval algorithms for a spaceborne W-/Ka- Doppler radar*
 - ❑ *Quantitative assessment of advantages and potential of alternative technological or algorithmic solutions*
 - ❑ *Multi-instrument algorithms*



Airborne simulators supporting cal/val



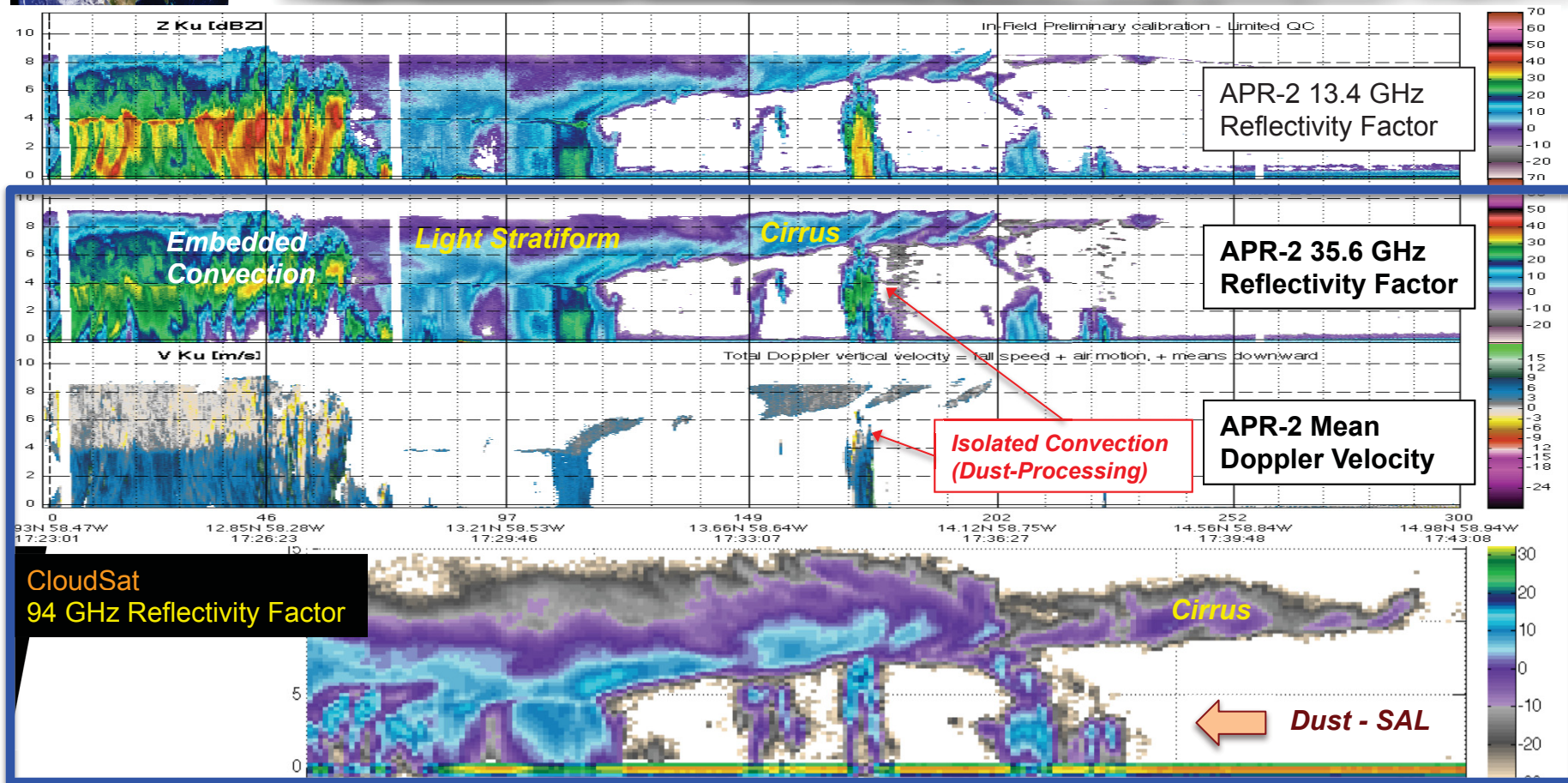
- ◆ Large datasets of X-/W-band and Ku-/Ka-band airborne Doppler radar data exist
- ◆ Very small datasets of colocated W-/Ka-measurements exist:
 - *Wakasa Bay Experiment 2003, APR-2 (Ku-/Ka-band, IIP'98) + ACR (W-band) on NASA P-3*
 - ***TC4 Experiment 2007, APR-2 on NASA DC-8 + CRS (W-band) on NASA ER-2. (Shown in this slide)***
 - *TC4 2007 and GRIP 2010, APR-2 underflights of CloudSat.*



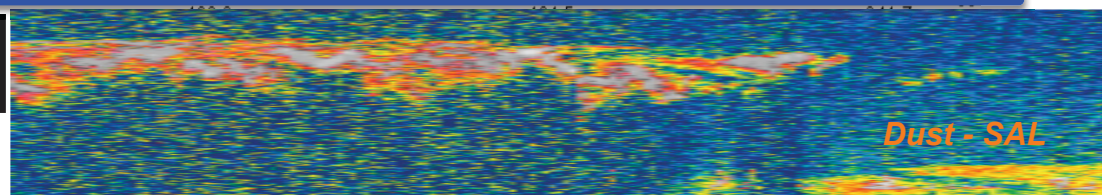
INSTRUMENTS	PROS	CONS	Readiness
ACR(W) + APR-2 (Ku/Ka, IIP'98) on DC-8 or P-3	<ul style="list-style-type: none"> • Safe/low cost, • Meets sensitivity • scanning 	<ul style="list-style-type: none"> • Only clouds < 10km altitude • Large (two radars) 	Ready, tested in 2003
CRS (W) + “H(iw)RAP” (Ku/Ka, IIP'04) on ER-2 (poss. GH)	<ul style="list-style-type: none"> • High-altitude • CRS well tested and meets sensitivity 	<ul style="list-style-type: none"> • not scanning on ER-2 • Large (two radars) • Ka-band needs upgrades to achieve sens. 	Planned readiness: Spring 2011
ACE Airborne Simulator (W/Ka/...) on GH or ER-2	<ul style="list-style-type: none"> • High-altitude, • scanning, • compact 	<ul style="list-style-type: none"> • At concept level • Development costs 	Submitted to IIP'10



September 21, 2010 NASA GRIP – A-Train Underflight ~ 13.5N 58.5W



CALIPSO
532 nm Total backscatter



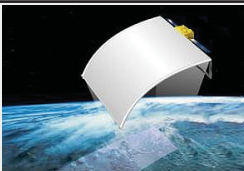
MODIS
11 μ m channel





Recommended Path Forward



	Flight Segment	Ground Segment	Cal/Val
Necessary for baseline implementation	<ul style="list-style-type: none"> -ACERAD Integrated Antenna System - ACERAD HPA: collaboration with SWOT - Concept maturity, cost/risk assess./analyses. 	<ul style="list-style-type: none"> - ACE Radar retrieval algorithm tests - ACE Multi-instrum. algorithms 	<ul style="list-style-type: none"> -Acquisition of W/Ka data + in situ samples -Analysis of existing datasets - Compact Airborne ACE radar
Recommended to reduce mission cost/risk	<ul style="list-style-type: none"> - Ka/W High Power Amplifier (mass, efficiency, lifetime) - Advanced Pulse compression techniques 	<ul style="list-style-type: none"> - Analysis of performance of advanced signal processing methods 	<ul style="list-style-type: none"> - Analysis of external active calibration facility
Recommended to improve performance margins & science	<ul style="list-style-type: none"> - Phased Array ("PR-2 style") at Ka- and W-band. - Ka-/W-band improved efficiency/packaging T/R MMIC - Ka/W-band reflectarray - Ka/W-band radiative structures - <i>Lightweight Deployable Antennas</i> 	 <ul style="list-style-type: none"> - Advanced retrieval algorithms (e.g., Data Assimilation based) 	<ul style="list-style-type: none"> - 3+ frequency, Doppler, Polarimetric, Scanning, Advanced Airborne ACE radar (relevant to NASA science beyond ACE)

Addressed in 2010 IIP proposals/SBIR calls, planned for future ACT/AIST/ROSES.